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Bricolage and Consultation: Addressing New Design Challenges When Building Large-Scale Installations

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ABSTRACT

We describe the many challenges faced when designing, implementing and embedding large-scale installations in a physical space, such as a building. A case study is presented of a distributed ambient display system intended to inform, lure and influence people when moving through the building. We outline the wide range of technical, user, aesthetic and practical aspects that need to be addressed; pointing out how many unpredictable problems can surface when going ‘big’, ‘physical’ and ‘out of the PC’. We argue that a different set of ‘non-user-centered’ processes are required. Furthermore, we propose a new design implementation approach that includes aspects of iterative design, but with the new processes of bricolage and consultation added for progressing the design.

Author Keywords

Design, implementation, bricolage, consultation, tinkering, public installation, Waterfall model

ACM Classification Keywords

H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

Interaction design has begun to broaden its horizons, embracing increasingly ambitious user experience projects that exploit emergent ubiquitous technologies [6, 12]. No longer constrained by a particular development platform (e.g., PCs, laptops), researchers are beginning to think ‘big’ and ‘outside the box’ in terms of what can be developed, using new do-it-yourself (DIY) hardware platforms and smart materials such as Arduino and Phidgets [3, 7, 8, 23]. One approach has begun to explore new ways in which digital information can be embedded into architectural spaces, such as office buildings, shopping malls, and homes, by constructing their own high-fidelity prototypes, and conducting in-situ studies. An early example of such

research, “Pinwheels,” was constructed using 40 interconnected fans, which spun in different patterns to represent levels of email traffic as patterns of wind [16].

However, while DIY technologies are enabling researchers to begin experimenting more with physical prototyping, scaling these up to large-scale installations in real-world settings can be a massive undertaking. There is little guidance available to deal with the challenges and potential pitfalls. The knowledge of experienced installation artists – for whom this kind of activity is more commonplace – is often tacit and experiential. Treatments of physical interaction design tend to focus either on small-scale prototypes [15] or on higher-level concepts like space and place [18].

Moreover, as commented by the developers of Pinwheels, ensuring an installation functions as intended is a “tremendous design challenge” [ibid. p112]. Many unforeseen obstacles can appear, including technical and logistical problems, e.g., breakdowns, incompatibilities, limited stock quantities, building services and administration [13]. These can have a direct impact on how much of the original design can be successfully implemented before a project deadline.

In this paper, we argue that the process of transforming an initial design concept into a physical installation is quite different from designing and implementing software. While the armory of prototyping techniques and user-centered design methods will continue to play an important role, the wider and often unpredictable set of challenges of going ‘big’ and ‘physical’ requires, concomitantly, other non-user-centered skills, steps and decision-making processes. Much envisioning of ‘what-if,’ followed by the weighing up of multiple trade-offs is needed, before and during experimentation with electronic components.

To illustrate our approach, we present a case study describing the many processes involved in the design through to deployment of a large-scale physical installation. The system comprises a distributed ambient display intended to inform, lure and influence people when moving through a work building. We describe how we moved from an initial design concept to a fully functioning and deployed

installation. We discuss the different processes involved and how a wider set of design decisions were juggled and ultimately resolved. Based on our experiences, we propose a new approach to the design-implementation process, that includes aspects of the original Waterfall model, and which suggests augmenting iterative design with bricolage and consultation.

BACKGROUND

Examples of large-scale physical installations that have been implemented in walls, ceilings, and floors, include Hello.Wall, which conveyed awareness information about people in the building using an array of glowing lights [24], ambientROOM, which provides subtle information using light, sound, and movement, in a confined space [31], and Datafountain, where three water jets varied in height to show exchange rates for different currencies [19]. Common to these new types of display is the goal to make ‘invisible’ information accessible in a way that is aesthetic, public, fun, informative, and compelling.

While the functionality and user experience described is often impressive, little attention is given specifically to the implementation process and the challenges that were faced. It is difficult to find out how these installations were constructed and what obstacles had to be dealt with. The odd comment in a paper suggests that serendipity and much trial and error may have played a significant role. Also, much experimentation with new materials and electronics is sometimes alluded to in order to build physical installations [26]. But what these are and how they can be incorporated into the design process needs more explication.

High-level physical toolkits are now becoming available to help interaction designers to build physical products and installations, especially those who are not familiar with the more build-centric disciplines (e.g., robotics, industrial design, etc.). These combine hardware and software components with the aim of making prototyping easier and more flexible. Examples include Arduino [3, 7, 8], Phidgets [23], Smart-its [9] and iStuff [4]. Middleware infrastructure toolkits have also been developed to help with the programming involved in connecting sensor-based and ubiquitous applications in wireless and mobile environments. Examples include Mobware [2], ECT [11] and CAMUS [21]. Commercial ambient displays, such as the Ambient Orb [1] and the Nabaztag [22] have also appeared, that can be incorporated into design projects with a small amount of programming and wiring.

While such toolkits and off-the-shelf products have enabled more researchers to develop and build a wider range of physical prototypes there are many other challenging concerns that need to be addressed as the scale of an installation increases. These include practical issues and logistical constraints such as power, networking infrastructure, safety and lighting [5, 14] – that are not problematic when building smaller scale prototypes. This requires learning or having access to a much broader range

of skills and knowledge, including building materials, construction techniques, electronic hardware, aesthetics, classical engineering, and even diplomacy. Additionally, it requires learning how to forage and shop for parts and materials in unusual places, for example, the plumbing section of the local hardware store.

THE CASE STUDY: CLOUDS AND LIGHTS

The goal of our research was to design a large physical installation that would be embedded in a new open plan building. The motivation behind the installation was to explore how increasing people’s awareness of tacit information through embedded ambient displays can change behavior. The behavior we selected for representation is one that everyone has to make several times a day: whether to take the stairs or the elevator when moving between floors in the workplace. We chose this particular activity because, firstly, it lends itself to being influenced at the point of individual decision-making and, secondly, the information can be made visible and public in terms of an aggregate representation of people’s choices. Our aim was to have an aesthetic, striking, and provocative installation as a permanent feature easily noticeable by everyone in the building.

Two kinds of ambient displays were decided upon: ‘Follow-the-Lights’ and ‘Clouds’. The first was intended to lure in subtle ways when walking towards it and at the point of decision-making. The second was intended as an aggregate display that could be glanced at when walking passed it. We describe below how the initial design concepts were derived and progressed.

(i) Initial design concept

Our initial design concept made use of scenarios, images, and text-based documents, to envision an innovative ambient technology that could change people’s behavior. It was developed in consultation with a professional interaction designer, who was not part of the research team. This was because it was considered important to bring on board someone who was impartial, and who had the expertise, creativity and understanding to be able to generate an innovative and attractive design but which was also feasible to implement. To provide the necessary background for her to develop a design spec, the motivation for the research project was discussed in relation to the importance of design aesthetics and the efficacy of persuasive technology in changing behavior. The designer also visited the building where the installation would be on display, and spent several hours taking pictures and considering possible ways the interior space could be augmented with ambient displays, as well as imagining how design possibilities would look from different perspectives. Finally, after discarding and distilling a number of alternatives, based on both pragmatic and aesthetic considerations, a set of detailed design sketches and animations were created, along with examples of the specific designs from which she took inspiration. The

research team agreed and was confident that they could implement the designs.

The research team took her design spec of Follow-the-Lights and Clouds-of Light as their blueprint (see Fig. 1). Follow-the-Lights was envisioned as an animated pattern of lights embedded into the carpet near the entrance of the building that would lure people away from the elevator and towards the stairs. The Clouds was envisioned as an abstract representation, depicting the aggregate of all stair and elevator usage in the building – in the form of two different colored clusters of spheres that were meant to appear like clouds. An inspiration for this work was *The Source*, which is a kinetic sculpture in the London Stock Exchange created by Greyworld [30]. The rationale here was that people in the vicinity would glance at the Clouds, triggering them to talk about and reflect upon what they thought it meant. The design rationale of these two representations was that a combined persuasive display paired with a public ambient display could work together to influence and raise awareness at both an individual and public level.

To transform the design spec into an installation we considered next how to build and set up the underlying sensor infrastructure.

(ii) Sensor infrastructure

Two types of sensor technologies were considered for tracking the numbers of building inhabitants using the stairs and elevators: infrared movement detectors and pressure mats. Infrared sensors were rejected because of the problems of mounting them in the appropriate locations. However, we found that the carpet tiles used in the building could be easily removed and there was a crawlspace beneath, so a sensor network was constructed comprising five pressure mats grouped into three locations at the base of the three staircases and two elevators in the building. The pressure mats were connected to three sensor hubs positioned under the floor.

Originally, the plan was to use wireless Sun SPOTs [29] to communicate information from the pressure mats to our

displays. However, we found that the building had too much concrete, metal, and existing wireless traffic, for this to work reliably. The search for a new solution resulted in using three Arduino boards with Ethernet shields, which allowed us to use the existing Ethernet connections in the crawl space beneath the floor. The positioning of these sensor hubs was largely driven by access to the existing power and network points, which were located underneath the floor. During prototyping, laptops were initially placed beneath the floor and used as temporary sensor hubs.

Early testing of the sensors revealed it would be impossible to accurately measure the number of people walking over a single sensor. Observations of how people used the space and body storming [28, 20] by the research team in the building revealed that people do not walk over them in a consistent fashion that can be reliably counted; multiple readings would be logged for people who sometimes stood on the sensors for a prolonged period of time chatting to one another, and for the trolleys used by catering, delivery, and cleaning staff. This inaccuracy actually proved to be serendipitous since having a system that was only approximate addressed potential issues related to privacy and surveillance. By collecting openly aggregate, anonymous, and approximate information it was thought that people within the building would not feel that they were being forced to use the stairs over the elevators.

However, it was still necessary to calibrate the sensor readings. For example, the elevators received more ‘multiple’ readings than the stairs, as people pushing trolleys have to take the elevator to reach the upper floors. A calibration was conducted by sitting in the space and manually counting the numbers of people taking either elevators or stairs at different times of the day over a period of two weeks. The resulting data was used to calculate a correction factor for each of the sensors.

(iii) Developing the Clouds Display

There were many challenges to creating a matrix of moving spheres to make them appear as two clouds – one representing stairs and the other elevator usage. This included: deciding on the materials; how to assemble them; the way they should hang; the way they should move; what they would actually represent; and how to hang them in the atrium space. To begin, we had to determine how the clouds would represent stair/elevator usage especially in terms of the available dimensions of height and distance. It was proposed that the more people using the stairs or elevator, the higher the corresponding cloud would be. If the two clouds were far apart, the usage of elevator and stairs would appear to be dramatically different. If they were close together it would suggest an almost equal number of people would be using either the stairs or elevator.

To test this design concept, some initial low-tech prototyping was carried out. A simple 3-D model was constructed, consisting of tomatoes and mushrooms hanging from a frame by lengths of fishing line (see Fig. 2).

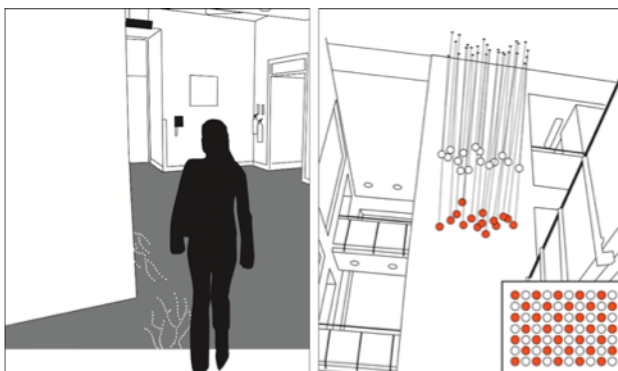


Figure 1: Design sketches for the distributed ambient influence display: Follow-the-Lights (left) and Clouds (right)

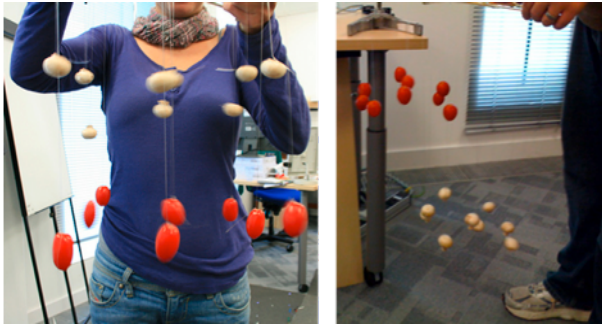


Figure 2: Low-fi prototypes of the Clouds design concept using tomatoes and mushrooms

The cloud of tomatoes could be easily moved up and down through the cloud of mushrooms in a manner similar to that of the concept in our design sketch. This model was suspended inside our lab and tested in several different orientations to see how clearly one could discern the two separate clouds and their intended meaning. This involved setting a particular orientation (e.g., tomatoes slightly above mushrooms or clouds side-by-side) and having people walk around the room or lie under the model to achieve perspectives similar to those one might have within the atrium. One question we debated was whether overlapping or side-by-side clouds were preferable. From the elicited reactions it was found that both could be understood as meaning different states, but that the overlapping arrangement was the most desirable in terms of aesthetics.

Stairs/elevator mappings Another implementation decision that had to be made was which kind of mapping to use between collected sensor data about stairs/elevator usage and cloud height. A simple graphical visualization was constructed to show the information being received from the pressure mats under the floor. The visualization shows four different mappings that vary in terms of showing the difference between the two measures (see Fig. 3).

These included a linear count of the totals for stairs versus elevators, the total counts of each squared, a ratio between the two counts, and the ratio squared. The squared scale shows a more dramatic change in the case of there being only small numbers of people. In order to gauge people's preferences for the different representations, a small study was conducted where several people were interviewed. The purpose of the installation was explained and they were asked to imagine walking into the atrium where they would see the clouds changing throughout the day. Most expressed a preference for the ratio-squared model, suggesting that it was more important that the difference between the clouds be obvious than that there was a change rather than there being an accurate readout.

Aesthetics and materials An important decision to be made was which materials to use to create the spheres. Again, the aesthetic was considered important, especially the quality of the materials used to construct the spheres. This is because an ambient display requires onlookers to accept the display

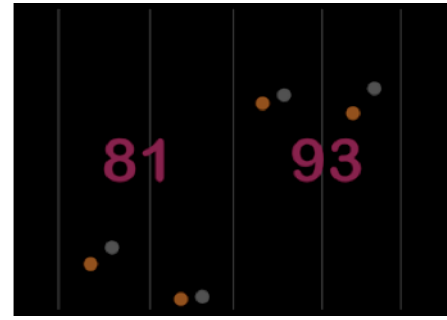


Figure 3: The different mappings used to represent the positioning of the Clouds

as a real aspect of their surrounding environment, rather than as a temporary research prototype [11]. If the display does not fit into the surrounding environment it will “stick-out” and not blend into the environment. Another big constraint was production time-scale and cost. It was necessary to decide upon the finished design of the spheres quite early in the construction process, which meant that any problems emerging from this decision would have to be worked around rather than reconsidered.

These requirements demanded much searching for, and consideration of, potential materials. Another consideration was the size of the spheres, which was determined by the size of the building. We decided that a large open atrium required a large display so that it was noticeable. Several spherical objects of varying sizes were hung over a balcony in the atrium to help gauge what the overall effect would be. Another health and safety decision was that the spheres be relatively motionless (rather than be moving around). This required that they be heavy enough so as not to be affected by air currents within the atrium.

We consulted with a number of suppliers before commissioning a single sample sphere from a local company. It was decided to construct the spheres out of fiberglass since this material is heavy enough not to move around in air currents. It could also be produced at a reasonable cost and timescale. We used the single sphere to test other components of the installation before commissioning a further 23 spheres. These took approximately a month to produce, which introduced significant constraints on the project.

The design specification described the Cloud as looking like a collection of particles suspended, almost magically, in mid-air inside the atrium. The aesthetic challenge was to find a way of hanging them so that they appeared as if they were not actually attached to anything. The health and safety challenge was to make sure the material was strong enough so that it did not snap under the weight and movement of the spheres. Making the right decision on this material was critical because the wrong solution would make the installation dangerous for those walking underneath. It was initially proposed to use some sort of see-through fishing line. This decision was based on several

hours of research, both online and through discussions with the staff in local fishing tackle suppliers. However, under thorough testing, the first kind of fishing line we had bought (despite the claims made online of its strength) proved to be too weak and unreliable. A strong, thin, fluorocarbon line (but more expensive) was finally selected.

Selecting and engineering the motors Another challenge was how to maintain an accurate reading of the starting and stopping positions when moving the spheres. The research team initially decided upon using stepper motors, as they allow control over the exact number of revolutions. To construct a motor array would require 24 stepper motors, a micro-controller to manage them, and a gearing system to reduce the speed and increase torque. While searching for these parts, it was discovered that constructing the gearbox and building a controller circuit for these motors would be more complicated than anticipated: no ready-made stepper motors with gearboxes were available from any of the available suppliers. On further consultation with another researcher, who had expertise in robotics, we decided to instead make use of simple DC motors, often used in robotics applications. These DC motors have built-in gearboxes, and provided the torque necessary to position the spheres as a cloud. This decision required rethinking how best to implement them, because there was no longer a simple way to accurately track the position of the spheres. The new solution required developing an array of cut-off switches, so that the motors would stop when the spheres reached the top of the atrium. The cut-off array in turn required a redesign of the controller circuit, and a redesign of the structure designed to hang the spheres in order to mount all of the switches.

This stage of the implementation involved further shopping online for new controller components and then assembling a moving part by tinkering with a motor, a switch, a sphere, a fishing line, and an Arduino connected to a breadboard – all mounted on a scavenged lighting stand. This setup worked when tested, but the wiring of the controller was unstable. This problem was discussed again, but this time in consultation with an electrical engineer who suggested simply adding a diode to each switch so that it would cut off power in one direction but still allow power to flow in the opposite ‘down’ direction. This suggestion was tried out and found to work well.

Another problem faced when using the Arduino component to drive the controller was its limited number of outputs. Further consultation with a colleague working on another Arduino project described how he had used a multiplexer component to drive multiple LEDs; he predicted that the same component would control multiple H-bridges. This circuit was prototyped successfully on a breadboard, and had the serendipitous benefit of providing the ability to control not only the direction, but also the speed of the motors. This proved to be useful in creating acceleration and deceleration curves to reduce the amount of strain on the motors.

After building a prototype circuit to test the components in a controller for one motor we then decided to simply multiply the same circuit components so as to have one each to control the 24 spheres. However, creating a circuit of this scale on a breadboard proved unwieldy. Instead, we specified the requirements for a larger circuit based on our experience of tinkering. Because of the strict health and safety requirement – any sphere must never be allowed to fail and fall onto someone’s head when walking or standing underneath the clouds – it was decided that we should outsource the final construction to a professional electronics workshop, who had the ‘expertise’ to produce a robust version of the ‘tried and tested’ controller circuit.

Assembling the components We then set about assembling the fiberglass balls into a cloud formation by hanging them using the fishing line in a 4 by 6 matrix (see Fig. 4). The design of the holding frame was discussed with a technician in the mechanical workshop who suggested using prefabricated aluminum struts to construct a cage that would support all of the spheres along with the motors that would raise and lower the spheres. These struts could be held together using a special angle bracket so that there would be no need for welding. This allowed for some flexibility in changing its size, as the frame could be reconfigured if necessary.

Scaling up However, at this state we encountered a significant problem. According to the manufacturer’s website, and some discussions with the product vendor, the geared DC motors purchased for the installation were well within the suggested operating limits. Once the motors had arrived a simple test prototype was set up to ensure they had the power necessary to lift the spheres, and that they moved at an acceptable speed. The tests proved positive and allowed a single sphere to be tested over several days. However, once all 24 motors had been installed to move the 24 spheres up and down and testing continued, some of the motors started to fail. This was a serious problem: on inspection of the motors we found that the internal gearing used teeth that were too small to handle the weight of the individual spheres despite having sufficient torque to move



Figure 4: The chassis frame that was built to support the matrix of spheres

them up and down. Thus, even though the product vendors were sure that the motors could do the job, they did not necessarily have the knowledge of how they would perform in this new context (the motors were sold primarily as a component for moving parts of robots).

This crisis necessitated a major rethink of the implementation, which had a knock-on effect on other aspects of the design. Additional time had to be spent researching and purchasing new motors and mounting brackets, as the previous brackets of the frame were customized to the old setup; the new motors were larger in size and did not fit into the existing frame. In consultation with technicians working in the mechanical workshop we decided that fabrication of custom brackets could be outsourced to them.

Mounting the Clouds in the atrium Many discussions were also held about the best way to mount the Clouds within the atrium. The design spec showed the spheres as descending directly from the ceiling, but in discussion with the local facilities manager and health and safety advisor this design was considered impractical to mount and the height unsafe. It was decided that an alternative solution would be to hang the Clouds at a lower height, by suspending them off the edge of a walkway on the second floor of the atrium. Once the frame with spheres had been assembled, a health and safety advisor was again consulted to confirm that it could be safely attached to the side of the walkway. Different methods for safely installing it were also discussed at lengths, including using ropes to lower it or a scissor-lift to raise it from the floor. In the end, the former was chosen, as the weight of the lift was too great for the floor in the building.

(iv) Developing the Follow-the-Lights Display

To implement the Follow-the-Lights display we decided to use a series of twinkly LED lights that would come on when someone approaches them (see Fig. 5). We also wanted to remain as faithful as possible to the initial design concept which was to have an aesthetically-pleasing flowing pattern that suggested organic growth toward the entrance of the stairwell. A key requirement was that the LEDs could be embedded into the carpet in such a way that they could withstand constant traffic from both people and trolleys. After examining the flooring, it was decided that the best way to embed the LEDs was to drill holes into a set of matching carpet tiles. This was tested by drilling a sample tile, inserting a few LEDs, and then subjecting the LEDs to several forms of stress: repeatedly walking over them, hitting them with a hammer; and jumping up and down on them.

Scaling up Once we were satisfied that the LEDs could handle a sufficient amount of stress, we sketched out a simple pattern derived from the initial design sketches. However, we could not afford the time to implement the pattern exactly as it was displayed in the design sketch – as it would have taken several hundred LEDs – so the pattern



Figure 5: Final implementations of Follow-the-Lights (left) and the Clouds (right)

was simplified, but with the original organic growing feel maintained.

The visibility of the prototype tile was tested to ensure that it was bright enough to attract people's attention as they approached it. Having thoroughly tested one tile, we then made a further nine tiles using the same design and wiring pattern of the initial LED-embedded tile. When we began to link the tiles together, however, managing the wiring became increasingly difficult. This was due to several factors we had not predicted, including, the complexity of dealing with four separate circuits wired in parallel; the wire to connect the LEDs being extremely thin and delicate; and the lack of a good component to use as a connector between the tiles. On several occasions, one person would lift a tile to analyze a problem and accidentally cause other problems in the surrounding tiles by either snapping a wire, breaking a connector, or dislodging one of the connections to a LED. What we had assumed would be a straightforward task (scaling up the tiles) actually proved to be very challenging.

Finally, once all of the carpet tiles were wired together and the light patterns were working we began to install them into the entrance hallway to the building. Unfortunately, the solder joints on the LEDs were somewhat sharp, and as the carpet was being installed, the joints began to cut through the backing we had applied to each. These joints then made contact with the aluminum subflooring causing short-circuiting whenever anyone would walk along the path. Solving this new problem required that we completely remove the carpet and consider a new strategy.

We decided at this point to consult with our contacts in the electronics department in order to develop a more robust wiring strategy. Unlike the motor problems, the experts had few suggestions for a "best way" – since embedding LEDs in a carpet was one of the more unusual projects they had been asked to consider. A potential solution was discussed involving a single power bus that all the tiles could connect

to, and a thin robust connector to connect the modular tiles to one another. Based on several constraints, the final solution was to cut channels in each tile to allow for a thicker gauge wire to be used. This proved to be a more effective strategy and was used for the final implementation.

IN-THE-WILD STUDY

Transforming the initial design concepts into a working installation took 9 months: prototyping, engineering and thoroughly testing the installation in order to ensure it was safe, robust and reliable. A 6-month study was also conducted to obtain a baseline of stair/elevator usage in the building. An ‘in-the-wild’ study was then conducted over an eight-week period to evaluate the building inhabitants’ and visitors’ perceptions of the effects of the displays on their behavior and to compare these with their actual behavior. A mixture of data collection methods were used, including observations and interviews *in situ* with people walking past the displays when in the building; an online survey sent to everyone in the organization and logging of actual stairs and elevator usage. Detailed findings and analysis are reported in [25]. An overall finding was that the distributed ambient display elicited much intrigue and discussion from both the building’s inhabitants and their visitors. The findings were conflicting, however, as to whether the ambient displays changed people’s stair/elevator behavior. On the one hand, few people admitted to changing their behavior in response to seeing any of the displays, while on the other, the logged data showed a large increase in the proportion of stair usage after installation. This finding suggests that the installation may have increased people’s awareness about stairs and elevators that, in turn, may have unconsciously nudged some people to take the stairs at choice moments – which they may subsequently not have remembered.

DISCUSSION: AN ALTERNATIVE DESIGN-IMPLEMENTATION PROCESS

The detailed case study presented here has highlighted how moving from initial design concepts to implementation when building a large-scale physical system is quite different from the normative iterative 4-stage (i.e., research, design, evaluate, build) approach often prescribed in Interaction Design [27]. A core difference is that our approach is more technology-centric than user-centered. Rather than gather requirements or establish needs from a specified user group we needed to make many on-the-fly decisions to be able to transform the initial design concept into an actual installation. These included which components to purchase, how safe they would be, how to manage a variety of environmental constraints, how to scale up, how accurate data has to be to represent an actual behavior, and so on. There was also much comparing of alternative plans and solutions for technical, aesthetic and ergonomic concerns. Having a Plan A and a back-up Plan B that were sketched and talked through with various experts and consultants was one of the main methods of progressing our design. Our decisions also had to be made

to fit a much wider set of concerns than traditional usability ones, including health and safety, cost, engineering feasibility, and aesthetic consideration. Juggling between these and ‘taking the plunge’ to opt for a particular plan such as a way of wiring required quite different ways of managing design trade-offs.

To accommodate these new concerns and challenges, we propose a design-implementation approach that emphasizes the central role of bricolage and consultancy. By *bricolage* we refer to the act of making resourceful use of materials that are ‘at hand’ and tinkering with them [17]. Whereas ‘at hand’ has traditionally been used to refer to what can be scavenged in the garage or the workshop, we use it more widely here to also refer to what can also be purchased online and in the local hardware store. From this perspective, there are potentially thousands of parts and components ‘to hand.’ The problem then becomes one of deciding which of these to select and tinker with, bearing in mind many factors including matching the design spec, cost, scalability, and robustness. Successfully managing these decisions requires new ‘shopping’ and ‘sourcing’ skills in addition to developing a strong rapport with experts in a variety of fields (i.e., sales reps, engineers, hobbyists, and various DIY communities).

By *consultation*, we refer to the process of asking for advice, an opinion, a suggested technique or method and for feedback from a variety of people with specific and general kinds of expertise, including vendors, engineers, health and safety representatives and local ‘all-rounders’. But increasing who is talked to beyond potential users and stakeholders can complicate matters since it requires determining which view, opinion, piece of advice, etc., should take precedence – especially since they can often be different or even in conflict. Trusting and interpreting the various points of view becomes integral to the weighing up of trade-offs involved in the decision-making process.

Based on our experiences, we suggest that developing a large-scale physical system is in some ways closer to the sequencing suggested in the Waterfall lifecycle model rather than the iteration promoted in user-centered design. Progress is seen as flowing steadily downwards (like a waterfall) through the phases of conception, initiation, analysis, design and construction. This perhaps is not surprising, given that the Waterfall development model originated in the manufacturing and construction industries, which involved building highly structured physical environments. Whereas it proved to be a poor fit and inflexible when applied to software development it appears to be a better match for the development of large-scale physical systems.

We suggest, therefore, it is timely to reconsider aspects of the Waterfall model in this new context, in particular, when considering how to manage constraints and how to sequence the various processes. One of these is the need to complete a process before moving onto the next one. The

reason being is that it can become too costly and impractical to change a design half way through a design process, having committed to a particular physical component. For example, in our case having decided on a certain configuration of the 24 fiberglass balls for the Cloud we commissioned a set of spheres that could then not be redesigned. It would have required buying a new set (too expensive) and starting from scratch again (too much effort and time). While the use of low-tech prototyping was helpful for exploring a number of alternatives before committing to a particular design, such as whether people could perceive, discriminate or understand the meaning of the displays, they could only go so far in enabling us to imagine how the real installation would appear to the inhabitants of the building.

Decisions that have to be made early on, such as purchasing parts that take weeks to arrive, can lock into a fixed design. Viscosity [10] becomes a central concern, where a decision early on can make something much more difficult requiring much more effort and time to change later on. It can also be simply too expensive and time-consuming to make a change after committing to a particular decision. It is simply not feasible to do the same level of user-centered iteration, hence the similarities with the philosophy behind the Waterfall model. User methods, however, are folded in where appropriate (in our case observing and body storming) to help progress the physical design.

We describe our proposed framework as ‘Bricolage and Consultation’. It describes the processes that are interweaved with the designing and prototyping phases and which are described below.

Designing: When fleshing out an initial research idea that needs to fit in with a place (in our case an open plan building), a research goal (in our case to raise awareness of stair/elevator usage) and a type of technology (in our case the use of ambient displays) it can be very valuable to consult with an interaction designer who is external to the project. Different members of the research team may often champion their own solution, which may not take into account the full range of concerns, constraints and challenges. Such external consultation can be more systematic and impartial, enabling the initial ideas to be developed into a ‘blue-print’ with a supporting design rationale that all have agreed on. In our case, several design sketches were proposed, discussed and one was finally agreed on, based on a number of factors, including cost, aesthetics, persuasiveness, and plausibility of implementation.

Observing: This is important to understand how people use a space over long periods of time. In our case, we observed people as they walked through the entrance of the building in order to help us determine where the optimal placement of the sensor mats might be. Also we observed people walking through the atrium space, logging their paths in

order to figure out the right place to install the Clouds display.

Bodystorming: This form of role playing involves the researcher physically putting themselves in the context of use for a particular design, such as walking through the space and trying to reason about how the project is going to function and trying to be a first time visitor envisioning what their own first reactions would be [28, 20]. We used this method in conjunction with observing.

Shopping: This is an important part of the design process where a significant amount of time is required to search for components and existing parts that can be repurposed. The process includes searching online forums, browsing catalogs, calling specific vendors, and discussing ideas with mechanical or electronic engineers, in order to find something that will satisfy the requirement, such as a sphere, a motor or a robust type of LED. When developing large-scale systems it is very unlikely that all of the ideal components exist or can be purchased.

Tinkering: This involves experimenting with the components that have been purchased to determine if they can behave in a manner sufficient to meet the need for which they were acquired. Sensor toolkits, such as Arduino, and middleware are now mature enough to use in actual installation but many components will also need to be designed and built from scratch.

Coding: As well as developing the software for the displays, programming different parts of the system to control the sensors can be required. In our system we had to write the code that relays the input from a particular sensor on to a specific motor, and capture data from an online source to be displayed.

Engineering: Unlike most software-centric development processes, physical computing requires considerable engineering. For example, this can involve working out how a sensor can be mounted to a structure and connected to a microcontroller, or the way in which a large physical display must be constructed to account for the weight of several large motors. This is where consulting with engineers is essential.

Calibrating: This is an important process if sampling input from the surrounding environment is required. For example, if the installation uses an array of sensors to monitor the amount of motion in a given space, it requires testing what sort of input the sensors are receiving. Compared with software development, where a developer can assume consistency among the inputs, a wide range of natural phenomena can affect physical sensors.

Prototyping: This is central to design where various aspects of the design concept are envisioned and evaluated. Low-tech materials are often used. In our case, we created a simple low-fi prototype to help visualize the way the two Cloud displays would move through one another. However, when implementing a physical system it is not possible to

mock up the whole system using lo-fi materials and instead other techniques are required.

Evaluating: An in-situ or in the wild study has to be carefully planned once the installation has been embedded into a space. In our case, it was difficult to evaluate the system without influencing the targeted group as the aim was to increase awareness and influence people's behavior. During the design-implementation process, we chose to interview people from outside of the building, and visitors on open days.

CONCLUSIONS

The design and installation process outlined in this paper has shown how many decisions have to be made to move from an initial design concept to implementation when developing a large-scale physical ambient display that is to be embedded in a 'lived-in' building. Moreover, these processes require a wider range of skills and competencies than those possessed by most researchers working within interaction design and ubiquitous computing. While many of the processes outlined above will be familiar to those working in different disciplines – for example they might be considered part of the craft skill of an installation designer – this knowledge is typically tacit.

Finally, a new design approach was proposed to help guide researchers when going 'big', 'physical' and 'beyond the computer'. It has much in common with the early Waterfall model but it also shows how various user methods can be folded in. It suggests a shift from focusing on iteration as being central to progressing a design (i.e., resolving trade-offs and choosing from alternatives) to focusing more on envisioning and experimenting through the interleaving processes of bricolage and consultation.

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